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Heat transfer and pressure drop study in transition regime for ZnO-H_2O nanofluid synthesized by green route

Dr. Basgonda Sonage [1,a)] and Dipak Bhoge [2, b)]

[1,2] Mechanical Engineering Department, Nagesh Karajagi Orchid College of Engineering and Technology, Solapur, Maharashtra, India
a) basgondasonage@orchidengg.ac.in
b)dipakbhoge@orchidengg.ac.in

Abstract. The demand of heat exchanging devices is increasing day by day in various applications like refrigerating, automotive, power plant and process industries. The work presented here narrates to the development of substitute heat transfer fluid called ZnO-Water Nanofluid. Dispersion of solid Nano particles in a base fluid enhances thermal properties of base fluid. In this work ZnO Nano particles are manufactured by green synthesis method from Aloe Vera. Characterization and thermo physical property of ZnO are studied in this paper. The size of Nano particles is measured by X-Ray Diffraction (XRD) and shape of ZnO nanoparticles are characterized by Transition Electron Microscope (TEM). Experimental setup is developed to measure heat transfer coefficient and pressure drop for base fluid and Nano fluid. Experimentation was conducted for different flow rates of base and nanofluid. Pressure drop is measured with piezometer tube and heat transfer coefficient is calculated from energy equation and heat transfer equations. The result indicates that 2.5% to 5.6% pressure drop between Base Fluid and Nano Fluid. There is enhancement in heat transfer coefficient from 6 to 9.5% for the Reynolds number ranging from 3100 to 3800.

INTRODUCTION

For enhancing the performance of heat exchanger there is need to develop alternate fluid for existing heat exchanger. An alternate fluid can be developed by adding solid nanoparticles having high thermal conductivity into the base fluid-water. Due to high thermal conductivity of nanofluid the heat transfer is enhanced which helps to reduce the size of heat exchanger and also to reduce the pumping power. However, detailed study about synthesis of Nano particle characterization, thermal properties, heat transfer performance and pressure drop is necessary to conclude enhancement of performance of heat exchanger with addition of Nano particles.

There are various synthesis methods available nowadays e.g. chemical, physical, biological and hybrid. Conventionally nanoparticles were manufactured only by physical and chemical methods. There are different methods of obtaining ZnO nanoparticles like mechano chemical process or precipitation process. Depending upon synthesis method the nanoparticle size are changes due to different properties (chemical and physical). ZnO nanoparticles commonly used in many applications like rubber, farmer, textile, electronics, photo catalysis and miscellaneous applications like criminology, production of zinc silicates etc. Different plants are used for biosynthesis of environment friendly nanoparticles such as the biosynthesis of ZnO nanoparticles by plant aloe Vera and Cathranthus Roseus.

Nanoparticles are synthesized by chemical vapor condensation method by Kim , J.C. (2004) [1] . Manish kumar and Sahu (2010) [2] have manufactured zinc oxide nanostructures by direct oxidation of metal. Ertan et.al. (2013) [3] observed zinc oxide is as an antibacterial material. Sonage and Mohanan (2012) [4] have synthesized zinc-oxide nanoparticles into water and ultrasonication.

Biosynthesis of nanoparticles gives monetary and environmental benefits over chemical and physical methods of synthesis. This paper focuses more on green synthesis methods of ZnO nanoparticles from aloe Vera, its Characterization and thermo physical property. For preparation of ZnO nanoparticles by using biosynthesis methods the specific Chemicals are required. Following chemicals are required for the synthesis of green nanoparticles from specific plant extracts [12]

1) Aloe Vera leaf extract
2) zinc nitrate hexahydrate
3) Ethanol
4) deionized water

BIOSYNTHESIS OF ZNO NANOPARTICLES

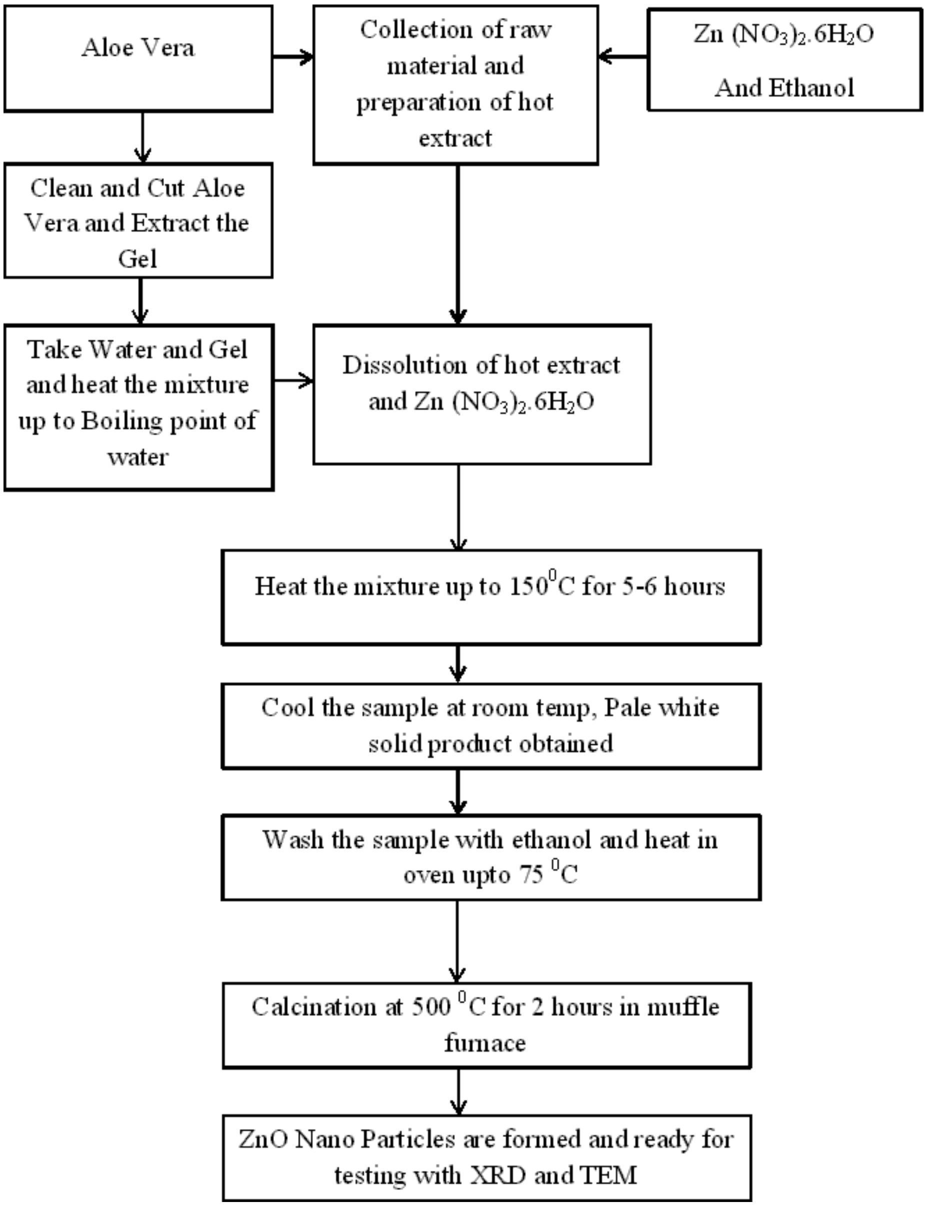


FIGURE 1. Process Chart for Biosynthesis of ZnO Nanoparticles

Nano fluids can be manufactured by one-step and two-step methods. In One-step method Nano particles are directly synthesized in base fluid-water. And in two-step method it can be separately synthesized.

The detailed procedure for obtaining the Zinc oxide green nanoparticles is explained elaborately below:
Aloe Vera hot extract was prepared by boiling of Aloe Vera leaves in distilled water at 100 ˚C at constant stirring of 4000 rpm. The resulting solution was filtered and the filtrate used as Aloe hot extract. The warm extract is used as reducing agents to synthesize nanoparticles. The $Zn\ (NO_3)_2\ 6H_2O$ is dissolved in the aloe extracts solution under constant stirring using electric stirrer in round bottle flask. With complete dissolution of the mixture, the solution is kept under vigorous stirring at 150 ˚C for 5–6 hour, allowed to cool at room temperature. The resulting white solid product is then filtered using suction funnel apparatus and washed with ethanol, then heated in the oven at 75 ˚C until almost dried to remove the solvent.

Annealing is done for getting the pure form of ZnO powder. Annealing i.e. calcination process means the heating substance at the constant temperature inside the furnace and cools the sample in the furnace only [9]. Ethanol is used during the filtration of powder and some ethanol remains in the powder. ZnO Nanoparticles are obtained after calcinations of the solids at 500°C for 2 hours in muffle furnace. For getting the nano sized powder, it is needed to keep it in furnace. How the annealing is done let us see. From 22.34 gm of the sample 9.12 gm nanoparticles is obtained.

The overall process of biosynthesis of ZnO nanoparticles is presented in the Figure1 in the form of flow chart as shown above.

CHARACTERIZATION OF ZnO NANOPARTICLES

The Dimensions of Particle is Measured Using XRD Technique

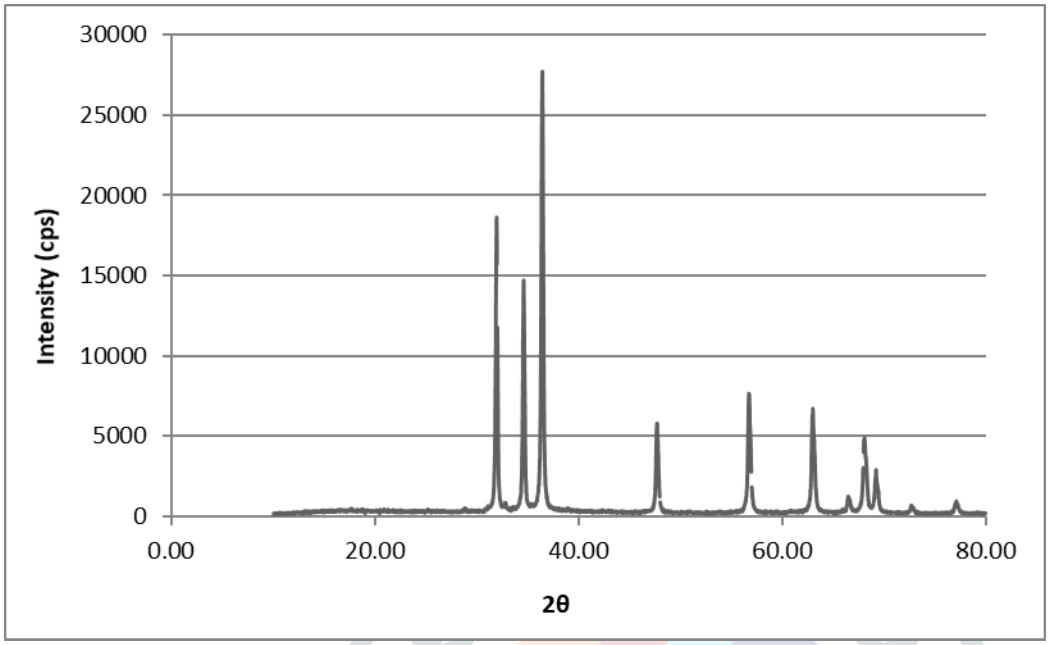


FIGURE 2 XRD Patterns of ZnO Nanoparticles

At the end of annealing process the white color powder is formed in the furnace. The size of the collected powder is determined by using XRD. The XRD pattern which is a graph of intensity verses glancing angle (2θ) is obtained as shown in Figure 2. The XRD pattern is coordinated with Joint committee for powder diffraction studies (JCPDS) of International center for Diffraction data, USA data file number 79-0206 to confirm about the presence of the zinc oxide. Obtained XRD pattern is matching with JCPDS data which confirmed that the powder is of zinc oxide. The results obtained by D. Singh, D. Pandey, R. Yadav (2012) [10] for ZnO is also matching with that from present work.

The Crystallite size of nanoparticle is determined by using the data from XRD pattern and De Scherrers equation (Eq.1). The size of zinc oxide nano particle is found to be 17nm.

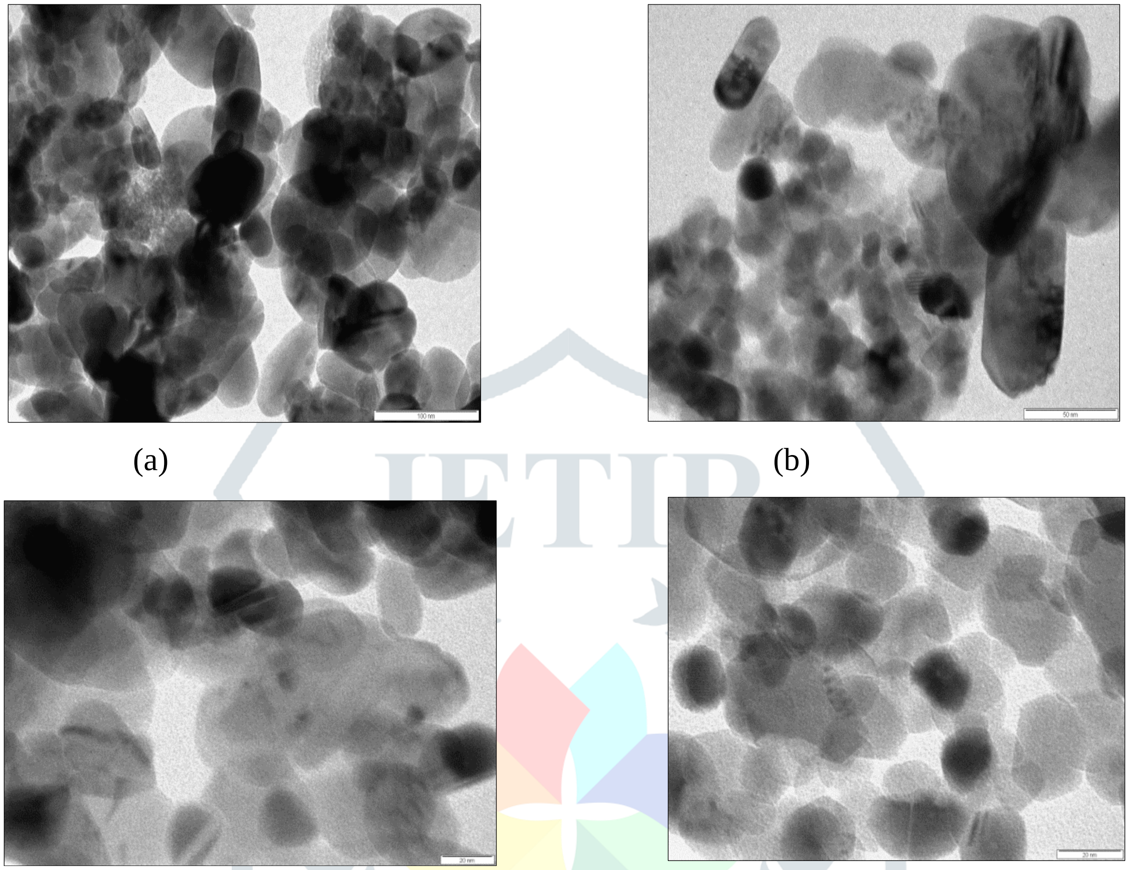
$$D = \frac{C\,\lambda}{\beta \cos\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where,
λ = 4.54056 Å
C = 0.90

CHARACTERIZATION OF ZnO NANOPARTICLES WITH THE HELP OF TRANSMISSION ELECTRON MICROSCOPY

The transmission electron microscopy (TEM) is used for best study of formation of nanoparticles. It gives particle size distribution, which is normally represented in terms of a mean diameter and a standard deviation. Both are not calculated in most studies; instead, a histogram of size distribution is presented along with the transmission electron micrograph. The detailed information on particle shape, phase transitions, two- and three- dimensional ordering, in-situ nano-measurements, and evaluation of other properties are possible using TEM.

The produced sample is tested in the IIT Bombay, India and observed under transmission electron microscopy (TEM) to decide about morphology of the particle. From the TEM testing it is confirmed that the sample is in the nano range. TEM images taken at different places of the powder and at different magnification are presented in the Figure 3 (a) to Figure 3 (d). From the Figure 3 (a) it is observed that nanoparticles remain in accumulated form due to high surface energy and high surface area to volume ratio. Figure 3 (b), (c), (d) indicates the shape of particle as mixture of spherical having different cross section similar shape obtained by N. P. T-Thienprasert et.al[11]. and G. Bhumi and N. Savithramma[5]



(a) (b)

(c) (d)

FIGURE 3. Images of Transmission Electron Microscope of ZnO Nanoparticles

Synthesis of ZnO-H_2O Nano fluid

Synthesis of nanoparticles is first step towards development of nano fluid by two step method. Zinc oxide nanoparticles synthesized by the process explained in above. For the present work, nanofluid is prepared by two step method. Zinc oxide nano powder synthesized by biosynthesis method is physically mixed in water (de-ionized water) in proper proportion to get nanofluid 1% volume fraction. Mass of nanoparticles required for getting a particular volume fraction fluid is estimated as per mixture theory. The required equation (2) is presented here for estimating mass of nanoparticles. Weighted quantity of ZnO powder is mixed physically in the de-ionized water to get nanofluid of required volume fraction

$$m_p = \left(\frac{\varphi}{1-\varphi}\right)\left(\frac{\rho_p}{\rho_w}\right) m_w \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

For the 500 ml of water as base fluids the mass of zinc oxide nanoparticles required is of 28.28 gm and for 1500 ml of water as base fluid the mass of zinc oxide nanoparticles required is 85 gm. Ultrasonication is applied for 6 hours in the steps of 20 minutes for proper mixing and to avoid agglomeration of particles. Settling of particles is observed within next 20 minutes after ultrasonication.

HEAT TRANSFER COEFFICENT AND PRESSURE DROP ANALYSIS

Experimental setup

The facility used for the current study is presented schematically in Figure 4 [13]. This project is developed to determine heat transfer and pressure drop characteristics of green nanofluid at constant wall temperature condition in transition regime. The experimental set up consists of test section, constant temperature heating bath, radiator, collecting tank, pump and auxiliary heater etc. The different elements of the test setup are assembled as shown in Figure 4. Inlet, outlet and surface temperatures are measured by RTD (PT100). Pressure drop is measured by Piezometer. A mass flow rate is measured by weighing the collected fluid in a particular time. Uncertainty analysis of mass flow rate measurement has been done. 96% of the time the measured value is accurate within ±3.50%.

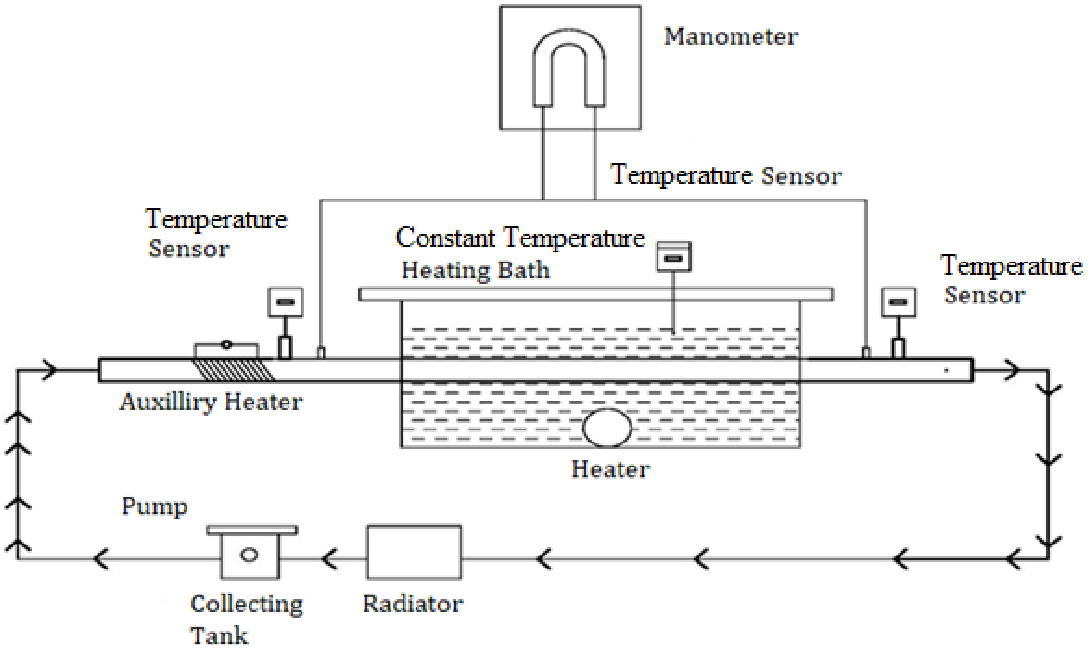


FIGURE 4. Experimental setup

Experimental Procedure

Experiments have been performed for different volume flow rate of nanofluid and base fluid-water. Observations are taken at steady state conditions for inlet temperature range of 29-30 ^{0}C, surface temperature range 78-88 ^{0}C and Reynolds number range 3100-3800 for both water and Nanofluid.

Koo and Kleinstreuer[8] have concluded that particle interface is less for nanofluid having volume fractions less than 0.5% and particle interaction is profound form volume fraction more than 1%. Nugyen et. al. [7] also concluded that due to hysterias behavior, the viscosity of nanofluid of 1% volume fraction strikingly increases beyond a critical temperature. As per the above studies the nanofluid having volume fraction less than 1% are considered for the present study. Experimental observations are reduced to get inner side surface heat transfer coefficient (hi). Following is the step by step procedure to determine hi and Δp. All thermo physical properties required for calculations are taken at bulk mean temperature. The range of bulk mean temperature is observed as 34-41^{0}C.

Following equations are used to calculate heat transfer coefficient and pressure drop for base fluid-water and nanofluid. Similar model presented by Yimin and Wilfrired[6].

$$\Delta T_m = \frac{(Ts-Tin)-(Ts-Tout)}{ln\frac{(Ts-Tin)}{(Ts-Tout)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$\rho_{nf} = \emptyset.\rho_p + (1-\emptyset)\,\rho_f \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$C_{nf} = \frac{\emptyset.(\rho Cp)p + (1-\emptyset)(\rho Cp)f}{\emptyset.(\rho p) + (1-\emptyset)(\rho f)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$Q = m.\,C_p.\,(T_{out} - T_{in}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$h_i = \frac{Q}{Ai * \Delta Tm} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Reynolds number is calculated from following formula.

$$R_e = \frac{m\,D}{A_c\,.\,\mu_{nf}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

At bulk mean temperature the thermo physical properties are calculated by data reeducations.

RESULT

Pressure Drop Characteristic

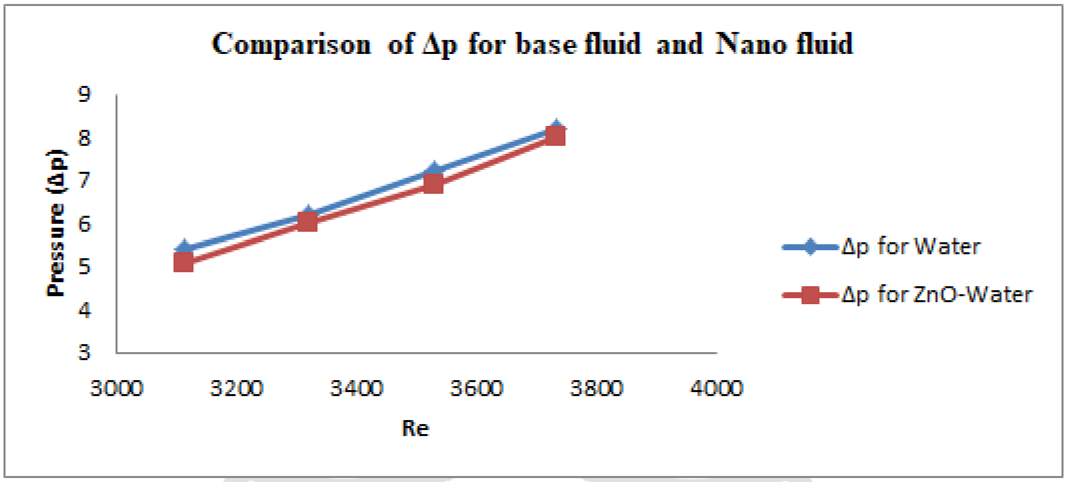


FIGURE 5. Graph of between p versus Re for water and ZnO-Water nanofluid

Comparison of pressure difference for Nano fluid and water is presented in graphically from Figure 5. From graph the trend is increasing Δp with Re. From the graph it is observed that very small enhancement in Δp. The change in Δp is due to Nano particle, fluid and wall interactions. Following are the reasons for very small change in pressure for nanofluid and base fluid. Based on Wang Model Nano layer of water is formed on the surface of Nano particles because of which it experience same frictional drag for Nanofluid as that of base fluid. The results obtained are consistent with the study of Koo and Kleinstreure[8].

Heat transfer coefficient

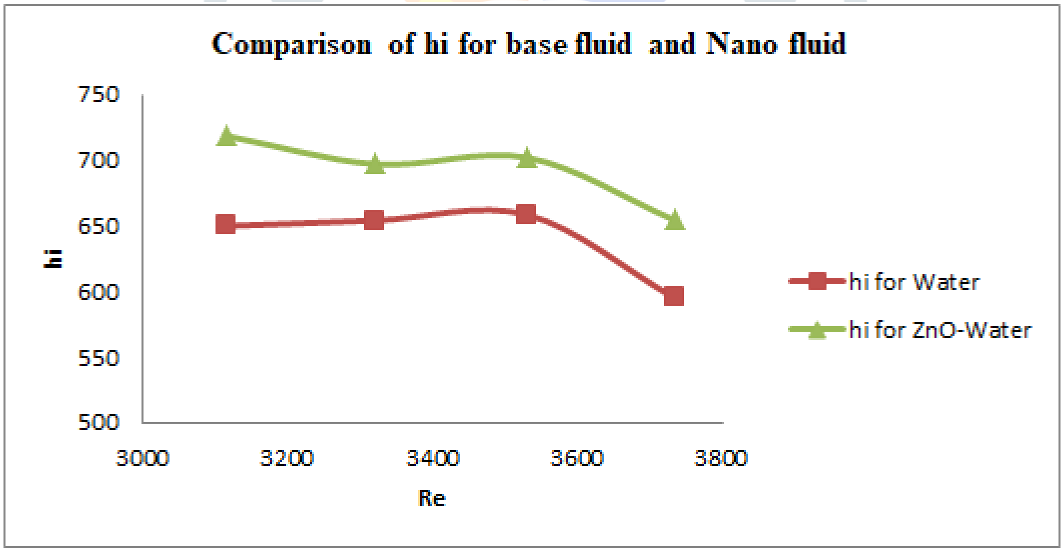


FIGURE 6. Graph of between hi versus Re for water and ZnO-Water nanofluid

Comparison of heat transfer characteristic vs Reynolds number for Nano fluid and water is presented graphically in Figure 6. The graph indicates nearly 6 to 9.5 % rise in heat transfer coefficient is observed over the base fluid water in Re 3100 to 3800 range and trend line is similar to base fluid. General trend of nanofluid is increasing compared with base fluid. The range of Re for transition flow is selected to study heat transfer in that regime. Enhancement observed is marginal but higher than base fluid. The difference in h for water and nanofluid is marginally steady indicating no random behavior of Nano particles.

CONCLUSION

Zinc oxide nanoparticles are manufactured by green synthesis method from Aloe Vera gel extracted from the leaf of the plant. Synthesized nanoparticles size is determined by XRD method & found 17 nm. TEM images are taken at different fields of the powder and at different magnification and observed that nanoparticles remain in accumulated form due to high surface energy and high surface area to volume ratio. The nanoparticles are having mixture of spherical shapes of different cross section.

ZnO-H2O have shown higher heat transfer coefficient over base fluid and small enhancement in pressure drop 2-5.5% for different flow rates. It indicates that about 1% addition of Zn-O nanoparticles in water gives better and energy efficient heat transfer. The enhancement in heat transfer coefficient is from 6 to 9.5% for the Re 3100 to 3800 range. Enhancement in heat transfer is marginal compared to enhancement in turbulent regime observed in several researches. Those behaviors indicate that ZnO-H2O nanoparticles are suitable for turbulent flow regimes rather than laminar and transition regime

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Nomenclature

ΔT_m : Logarithmic Mean Temperature Difference
ΔT_p : Pressure Drop in N/m^2
$\emptyset$: Volume Fractions of nanoparticles in nanofluid
ρ : Density (kg-m^{-3})
A : Area (m^2)
C : Specific Heat (J.kg^{-1}.K)
Re : Reynolds number
μ : Dynamic Viscosity (Pa.s)
β : Full width at half maximum of X-ray peak, radians.
D : Crystalline size in Å.
λ : X-ray wavelength in Å
C : Correction factor

Subscripts

nf : Nanofluid
s : Surface
o : Outer
i : Inner
w : Water

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